CR 73124

HOLOGRAPHIC INTERFEROMETRY WITH APPLICATIONS TO FLUID MECHANICS *

R. E. Brooks, R. F. Wuerker,
L. O. Heflinger, and C. Knox

TRW Systems Group
Redondo Beach, California 90278

Presented at the International Colloquium on Gasdynamics of Explosions, Brussels, Belgium, September 20, 1967

Slide 1 Unlike a conventional camera which records only the image of a focused object, the hologram records the complex wave pattern scattered from a laser illuminated object. At a later time the hologram can reconstruct the recorded waves, faithful in both amplitude and phase. The completeness of the hologram process allows one to make observations on the reconstructed waves in the same way they would be made on the waves scattered from the real object. Thus, in an optical sense, the hologram provides a close substitute for having the real object itself available for examination.

Slide 2 The faithfulness of the holographic process prompted Horman in 1965 to propose the use of a reconstructed test beam in the Mach-Zehnder interferometer in place of the real test beam. For this purpose he proposed to make a hologram of the test beam and subject and then to reconstruct the beam in the interferometer. The advantage of using the artificially-generated test beam is that the interferometric measurements can be carried out away from the test environment, without any loss of flexibility in examining the subject.

Slide 3 Going a step further, one can as well synthetically generate the comparison beam with a second hologram. In fact, one can then dispense entirely with the Mach-Zehnder arrangement and generate each hologram in the same beam at different times. When this is done, the interferometer becomes a common path interferometer, sensitive only to <u>changes</u> in the object. An economically important advantage of the common path interferometer is that imperfect optical components can be used without affecting the observed interference pattern. It also permits a diffuser to be used in the beam. By illuminating the object with diffuse light, one can view the interference pattern corresponding to different viewing angles.

Slide 4 Going another step further, the two holograms containing the two beams to be interferometrically compared can be recorded on the same hologram plate by making a double exposure. Because the two hologram patterns are "locked" together, the reconstruction procedure is not at all critical, and so long as only the desired changes occur between exposures. The apparatus is self-aligning. The accuracy of the interferogram is not affected by physical distortions of the hologram, allowing the use of photographic film for the hologram.

Slide 5 Here is an example of double-exposure holographic interferometry showing the infinite fringe interferogram of the shock layer surrounding a 22-250 caliber bullet traveling 3,500 ft/sec in the air. One exposure was made before the bullet was fired. The second exposure was made just as the bullet and its shock envelope passed into view. Tipping of the bullet causes an asymmetry in the interference pattern. The hologram was recorded using a Q-switched ruby laser and was reconstructed with a He-Ne gas laser. A diffuser behind the subject permitted it to be viewed from many different angles, although the slide was made by photographing it at only one angle.

Slide 6 A second example shows a similar bullet which has just passed through a sheet of 0.04 mm brass shim stock. When viewing the original hologram, the spatial configuration of the small fragments is readily apparent due to the three-dimensional nature of the reconstruction. Of interest here are the small fractional fringe displacements associated with the small fragments. Note the particle on the left slightly above center which is nearly in focus in this copy. The particle's wake appears as a light streak. Note also the shock from this particle and its extension into the shock layer of the main bullet. Within the shock layer of the bullet, the displacement of the main fringes by the small particle's shock is only about one-fifth of a fringe.

Slide 7 This slide shows an event nearly identical to the previous. On the original hologram it is possible to trace the outline of the shock wave which has passed through the shim stock. It occupies a position almost symmetrical to the reflected shock appearing above the shim stock. The transmitted shock can even be traced into the region outside the bullet shock layer.

Slide 8 Next is an example of double-exposure holographic interferometry showing the infinite fringe interferogram of the shock bubble resulting from a 20 joule capacitor discharge in air. The test exposure was made 50 microseconds after initiation of the discharge. The diameter of the spark balls is 9 millimeters.

Slide 9 This slide shows the interferogram resulting from the interaction of the shock wave of a 22-250 caliber bullet with the shock wave generated by the discharge of a low inductance 10kv - 1/4mfd capacitor.

Slide 10 Here is an interferogram showing the moving combustion front in an acetylene-air mixture two milliseconds after it has been ignited by a miniature spark plug. Note the effect of the wire electrode on the interference pattern.

Slide 11 For this case, the combustion was initiated from within a plexiglas cylinder. The interferogram shows only the differences in the two exposures, one made before ignition and the second shortly afterwards. The fringes on the plexiglas cylinder are due to its displacement resulting from the force of the expanding gas.

Slide 12 This slide clearly shows the use of the double-exposure holographic interferometry for making differential interferometric measurements. The subject is a light bulb. One exposure was made with the filament cold and the second exposure was made with the filament heated. The difference between the two exposures is due only to density changes in the heated filling gas and the interference pattern showing this change is accurately displayed interferometrically in spite of the poor optical quality of the glass bulb. If one were to attempt to observe the effect of the heated gas with a conventional interferometer, the pattern due to the glass envelope would be so severe as to obscure the fringes due to the gas.

Slide 13 All of the interferograms shown in the preceding slides were made from holograms recorded using a Q-switched ruby laser for illumination. The pulse length was about 100 nanoseconds. The principal difficulty in using the ruby laser for holography is its poor coherence. This slide shows an optical schematic of the hologram recording apparatus which was used. The complexity results from the need to spatially and temporally match the two beams forming the holograms to a degree demanded by the incoherence of the laser. Each ray from the laser is split; one part passes through the reference beam to the hologram; the other part is scattered by a diffuser and illuminates the subject located between the pair of large lenses and the hologram. Because the diffuser is focused onto the hologram, the scattered rays are recombined at the hologram with each other and with the reference rays. Because of this recombination process and equal scene and reference optical path lengths, only local coherence is required of the laser.

Slide 14 The final slide shows a photograph of the actual apparatus used. The holograms were made on Kodak spectroscopic plates, Type 649F, 4 x 5" in size. The resulting hologram of the diffusely illuminated subject can be viewed over an angular range of 40°. Because the interferometer is common path, inexpensive optics were used for the apparatus.

---

* Work reported upon in this paper was supported in part by the TRW Systems independent research program and by NASA/Ames (Contract NASW-1572).

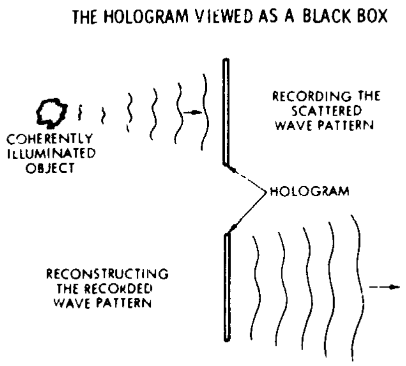


Figure 1

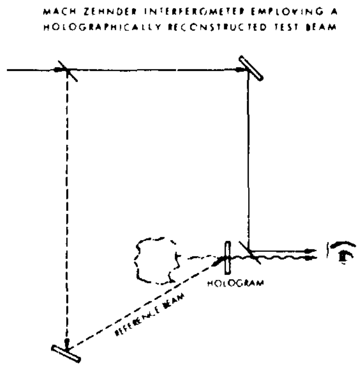


Figure 2

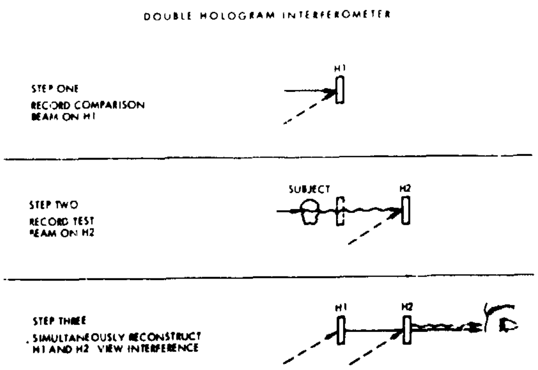


Figure 3

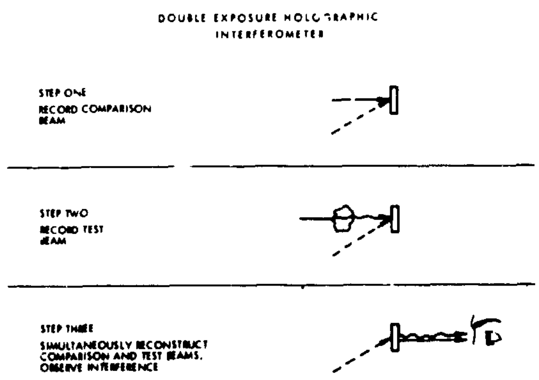
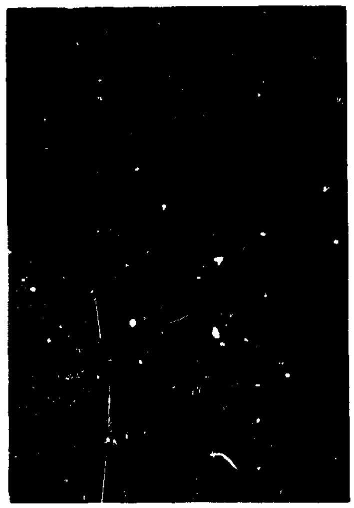


Figure 4

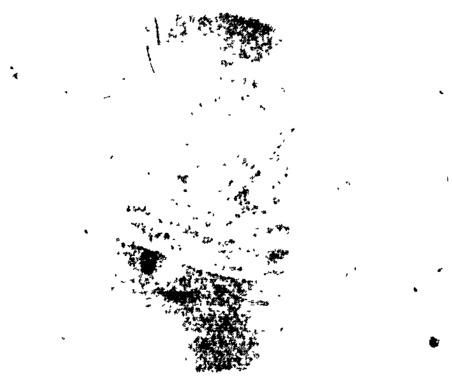


Courtesy of NASA

Figure 5

Courtesy of NASA

Figure 6



Courtesy of NASA

Figure 7

Figure 8

Figure 12

Figure 9

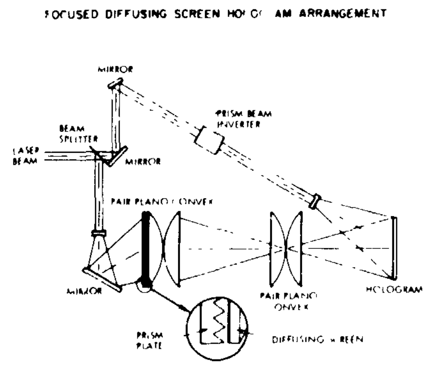
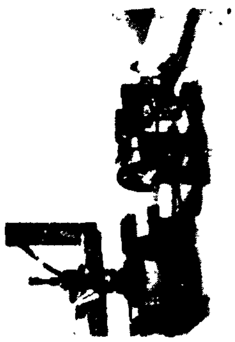


Figure 13

Figure 10



Photograph of a "focused ground glass" holocamera used to make 4 x 5 inch - 40° viewing angle holograms with the radiation from a Q-switched ruby laser illuminator.

Figure 14

Figure 11